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AN ANALYSIS OF VISUAL TASKS IN HELICOPTER SHIPBOARD LANDING

K. S. Berbaum, Ph. D. and
R. S. Kennedy, Ph. D.

Essex Corporation
1040 Woodcock Road
Orlando, Florida 32803
(305) 894-5090

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The purpose of this research effort was to identify visual research issues concerning helicopter landings, particularly the hover phase, for future study in the Visual Technology Research Simulator (VTRS) program. Identification of salient visual issues is a step toward surfacing equipment features that can be modified and studied. As we discussed the task with pilots, reviewed NATOPS manuals, and witnessed simulations, it became apparent that the visual task may differ depending upon whether: experienced or inexperienced pilots are flying; a simulator or an aircraft is flown; the environment is day or night; the pilot sought to acquire or maintain a skill level. As a way of limiting this broad project, we elected to review intensively a scenario involving a highly experienced operator flying dusk/night approaches in a simulator. The Naval aviator we selected was prompted by another aviator more familiar

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with our objective who dictated verbal protocols of his visual and control activities during several landings. These protocols were sorted into ten phases in order to correspond to increasing distances in the landing task and the visual information processing within each stage was described. Therefore, the stages are delimited in terms of range or altitude from the ship. We believe the most useful outcome of this analysis will be a list of visual cue augmentations that may be implemented and studied over the various stages of landing. These findings complement recent VTRS experimental studies of the hover-to-landing task (Westra and Lintern, 1984), and are in good agreement with those results. Future efforts should broaden the protocol analyses with more pilots and other select scenarios.

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PREFACE

The purpose of this research effort was to identify visual research issues concerning helicopter landings, particularly the hover phase for future study in the Visual Technology Research Simulator (VTRS) program. Identification of salient visual issues is a step toward surfacing equipment features that can be modified and studied. As we discussed the task with pilots, reviewed Naval Air Training and Operating Procedures Standardization (NATOPS) manuals and witnessed simulations, it became apparent that the visual task may differ depending upon whether: experienced or inexperienced pilots are flying, a simulator or an aircraft is flown, the environment is day or night, the pilot sought to acquire or maintain a skill level. As a way of limiting this broad project, we elected to review intensively a scenario involving a highly experienced operator flying dusk/night approaches in a simulator. The Naval aviator we selected was prompted by another aviator more familiar with our objective who dictated verbal protocols of his visual and control activities during several landings. These protocols were sorted into ten phases in order to correspond to increasing distances in the landing task, and the visual information processing within each stage was described. Therefore, the stages are delimited in terms of range or altitude from the ship. We believe the most useful outcome of this analysis will be a list of visual cue augmentations that may be implemented and studied over the various stages of landing. These findings complement recent VTRS experimental studies of the hover-to-landing task (Westra & Lintern, 1984) and are in good agreement with those results. Future efforts should broaden the protocol analyses with more pilots and other select scenarios.

Our approach has several limitations. 1) There may be visual cues outdoors that have not been included in the simulators we used. 2) Protocol analysis may not reveal visual cues that are important for performance but which pilots are not attended to consciously (in the sense of being able to report them). The first limitation could be addressed by repeating the experiment in a landing outdoors. Neither limitation may be a major deficit because many of the important visual cues are artificial rather than natural, and because it is unlikely that the task could be performed successfully without these cues. The cue augmentations for simulator training which we propose for further study are augmentations of artificial cues outdoors.

This document was written by and primarily for behavioral scientists in simulation R&D who have concerns for the visual and perceptual requirements of the helicopter hover task and is intended to be read in the order presented. However, we believe that simulation engineers and computer scientists would profit by reading the paper in a different order. We are recommending they jump from the Abstract to Table I; then Table II; then proceed directly to the Discussion; and then return to the Introduction, Method and Results, and Narrative.

SECTION I

INTRODUCTION

For the acquisition and maintenance of flying skills, simulators enjoy and deserve a reputation for having economic, safety, and educational advantages over total training in operational systems (Orlansky, 1984). The advantages of simulators are so great that simulators would be an important part of flight training whether or not care is taken in the specification of their design criteria. However, greater cost effectiveness can be achieved if equipment and instructional features are deliberately studied from the standpoint of how they influence training. Image generation and presentation is one of the most important and most costly elements in simulation technology, and realism and fidelity are factors which are highly desirable. The Visual Technology Research Simulator (VTRS) was designed in order to combine the emerging technologies of advanced computer-generated displays, vision and visual perception, transfer of training, skill acquisition, and experimental design (Collyer and Chambers, 1978). The recent history of this program has emphasized carrier landing and air-to-ground bombing scenarios in single experiments that examine combinations of variables in relation to training effectiveness.

Concern for the difficulties associated with the helicopter hover-to-landing task aboard seagoing frigates (Del Babb, 1983) has recently prompted interest in study of these scenarios. The most recent experimental effort at VTRS was undertaken to identify equipment features promoting the best performance in helicopter shipboard landing (Westra and Lintern, 1984). That study examined several equipment features (viz., ship detail, noise cuing, g-seat cuing, field of view, sea state, and visual display lags) in pilots with either high or low levels of experience. Ship detail and pilot experience level were found to influence performance.

The present study was conducted to complement Westra and Lintern (1984), and was meant to serve the same purpose as a report by Hennessy, Sullivan, and Cooles (1980). The latter deals with critical research issues and functional requirements for simulator V/STOL training. Our original plan was to perform a similar analysis for the helicopter hover-to-landing mission. The interested reader is referred to the pioneering report of Hennessy et al. (1980), for issues that we will not deal with such as unique maneuvers and coding of information.

Our broad intention was to infer visual requirements from a content analysis of the landing task and from the visual perception literature. We expected that an analysis of the task would reveal visual functions which could govern performance. From this analysis we planned to compare and integrate the inferences from our study with the empirical outcomes of Westra and Lintern (1984) so as to propose research issues for subsequent study ay VTRS.

The method originally adopted was to list the psychophysical sensitivities for the obvious visual dimensions (e.g., monocular movement parallax, movement slant perception) as a function of distance throughout an approach. At the beginning of the approach there are several visual dimensions that potentially could be used. For example, familiar size could be important following first sighting the ship by its wake because of the many potentially familiar parts: the profile of a ship, the bulkheads, the hangar doors, humans standing on the flight deck. During the last 300 feet of a landing there are many potential cues, and the pilot may use several of them to confirm his judgments. Motion parallax, flow patterns, motion in depth, binocular motion in depth, and familiar shape are among the possible late approach cues. Some of these are potentially very powerful, but may not be used in this task. As we proceeded with our analysis, we realized that without knowing more about the visual cues that experienced pilots actually use in the landing situation, an analysis of sensitivity as a function of distance would be of limited value.

We looked to the more formal methods of task description and analysis. Several approaches are available in the research literature dealing with methods for analysis of tasks into behavioral components. Chief among of these is the task taxonomy of Fleischman (1967, 1975), position analysis of McCormick and Jeanneret (1984), behavioral and information taxonomies of Christianson and Mills (1967), Critical Incident Technique of Flanagan (1954), as well as Protocol Analysis of Newell and Simon (1972). We settled on protocol analysis because it appeared to be a very useful shortcut and an intermediate step between full specification of all variables which may take a long time to assemble, and the alternative of specification of physical reality (which implies we do not know how to abstract the task). Using an experienced pilot within the situation gave us a way of distinguishing cues that are AVAILABLE from cues that are USEFUL in performing the task. We assume in this that an experienced pilot, having made numerous shipboard landings, has learned to select those stimuli which are most helpful and informative for landing. Cues that are salient and useful are attended to; cues that are available and potentially informative but are not the most informative cues available are not attended to.

For the purpose of specifying the utility of visual cues for helicopter shipboard landing in this project, we could have addressed one of several scenarios: The visual cues which are useful for learning to fly an approach, or performing an approach for novice or expert pilots in a simulator or outdoors in actual flight in day or dusk/night. This dichotomizing could extend to include other dimensions like limited Instrument Flight Rules (IFR) or Visual Flight Rules (VFR) etc., ad infinitim, but we stopped with the possibilities of Table 1. We recognize that these are not independent or exhaustive, nor are they all equally frequent or meaningful; we sought merely to delimit the problem. Therefore, we characterize the visual cues that are useful for skilled persons performing a simulator night (dusk) approach in terms of the ranges at which the visual cues become useful in vehicle guidance. Ultimately, we would hope to improve the way these cues are employed in landing an aircraft aboard a real ship. However, we expect that studies yielding the highest payoff performed in VTRS may reveal whether new adaptive display features will be valuable in training.

TABLE 1. FOUR DICHOTOMIES OF THE HOVER-TO-LANDING TASK WHERE DIFFERENT VISUAL CUES MAY GOVERN PERFORMANCE

		Simulator		Aircraft	
		Day	Dusk/Night	Day	Dusk/Night
NOVICE	Learning	___	___	___	___
	Performing	___	___	___	___
EXPERT	Learning	___	___	___	___
	Performing	___	X	___	___

We have selected the Light Airborne Multipurpose System Mark III (LAMPS MK III) as an example of the helicopter shipboard landing problem for analysis because of its currency and importance (Del Babb, 1983). Our objective is to determine which cues are likely to contribute to vehicle guidance at various distances as the ship is approached. There are several limitations to this approach: a) not all persons may have the same sensitivities for the different cues, b) different strategies may be applied in cue selection, c) the salience of visual cues might not be the same in novice vs experienced pilots or simulator/real aircraft, etc., d) there may be interactions between visual cues.

SECTION II

METHOD

To discover what visual cues are required for landing outdoors, and thereby assess those dimensions that are important to provide in simulators, we collected and analyzed a verbal protocol obtained from an experienced helicopter pilot during landing. The protocol is a taped record and transcription of the pilot's verbalizations during the course of the landing. Protocol analysis is a methodology popularized by Newell and Simon (1972) and their colleagues at Carnegie Mellon University. It is particularly useful in analyzing phenomena that exhibit strong historical dependence.

Protocol or task analysis may be used to identify fundamental visual operations and the driving stimuli in vivo, in a complete landing sequence, which can later be investigated in isolation with greater experimental precision. Protocol analysis may serve to identify opportunities for augmented feedback in training. In order for augmented feedback to be of value in a complex task like piloting a helicopter from as much as several miles out to landing, the augmented cue must be relevant for the visual task which is being performed at a particular distance. For example, if we wished to provide an augmented cue for lineup behind the ship, it would be inappropriate to provide this cue before the 2-1/2 mile range had been achieved because in ordinary flying at sea these visual cues are not visible before that distance. Protocol analysis of a landing scenario will reveal a series of visual tasks against a time/distance line. The visual cues required for these tasks become prime candidates for augmentation to improve: a) performance - a person's ability to fly the simulation, or b) acquisition - the amount of time it takes him to reach some level of performance in the simulator.

In Newell and Simon's work, the protocol of the single subject is analyzed and represented first as a problem behavior graph and then as a specific computer program or production system. A problem behavior graph represents what the subject knows and what perceptual, cognitive, and response operations are being applied as a function of time. The experimenter infers what the subject knows from his verbalizations according to a systematic and formal set of procedures, together with the experimenter's knowledge of language and his ability to extract meaning. It should be emphasized that this is not simply introspection. Only the most obvious components of meaning are used. The protocol, which is a record of utterances at time t, indicates states of knowledge and cognitive (information processing) operations at particular times; it is not a retrospective account. The subject doesn't theorize about his own protocol as he dictates it. He simply verbalizes what he's doing as he does it. The program or production system is a sequence or list of primitive operations; it is a theory of the subject's behavior. A protocol may be expected to produce the highly specific theory which may be viewed as a single data point (one per subject) for testing more generalized theory.

Identification of visual operations as a function of distance are, of course, the most important to identify for current purposes. This sort of analysis of the landing task is needed because the operations are sequentially dependent in much the same way as are the operations in problem solving. The experimenter calls out distance information as the pilot calls out where he's looking, the information he's trying to get, what aspects of the scene he is observing, control functions he is initiating; in general, what he is trying to do. The protocol will be our record of the pilot's activity. We will select excerpts from the protocol from several landings that are relevant to identifying visual cues that the pilot uses. These excerpts will form the basis of an analysis of stages of visual information processing during landing.

SECTION III

RESULTS

Ten successive stages are apparent in the protocol. The following table (Table 2) lists these stages an^ the distances from or above the flight deck which define the

TABLE 2. TEN SUCCESSIVE STAGES AND RESPECTIVE DISTANCES OF THE HOVER TASK

Stage	Distance	Label	Primary Tasks
1.	5-4.5 miles	"sighting"	sighting the ship to confirm TACAN
2.	4.5-2.5 miles	"instruments"	navigate to the back of the ship using TACAN
3.	2.5-1.5 miles	"lineup"	adjust horizontal location relative to ship
4.	1.5-1.2 miles	"red/yellow interface"	watch for amber ball to begin descent
5.	1.2-.25 miles	"decelerate" (instrument) (visual)	monitor deceleration (from instrument) monitor lineup and ball color (visual outside)
6.	.25-fantail	"approach" (visual)	visual deceleration approach monitoring
7.	fantail-15'	"creep"	slowly move across fantail to hover above flight deck
8.	hover at 15'	"preliminary hover"	maintain height, position over deck
9.	hover at 7'	"hover tension"	application of tension through cables - final centering
10.	rast landing	"pull down"	application of 4000 lbs through cables

These stages are somewhat arbitrary. Someone might argue with the exact cutpoints. However, they do provide a structure for the analysis.

Our goal in analyzing the protocol is to identify the visual cues that need to be provided by a simulator visual system in order to properly simulate the landing scenarios. In the following section we present excerpts from the protocol which address this question. We then identify primary visual features for the stage.

STAGE 1: 5.4.5 MILES, "SIGHTING"

"What the pilot is doing here is periodically looking out his right window to see if he can pick up the ship yet.".... (Appendix A, II)

"...my peripheral scan will be through the visual system trying to establish in part where the ship is - all pilots have a tendency to rely on eyesight above and beyond everything else that's given."....

"...you're able to differentiate a red light in the upper left-hand corner; you see a green flashing that indicates a deck status and you see what looks like just a white dot. If you consider most pilots have reasonable eyesight, but that white dot is actually going to break itself down into your lineup line itself as we get a little bit closer in. So the pilot looks for the white dot out there and tries to make sure on instruments he's able to line himself up behind the ship..." (Appendix A, II)

"...Periodically I look out the window and I'm definitely able to pick up the dots on the horizon, indicating that the ship is there. (How far are we out now?) We're presently a little over 4-1/2 miles..." (Appendix A, III)

The first visual job is to detect the ship location. This visual search is largely guided by TACAN indications of ship direction and distance. The visual sighting is primarily to confirm these indications. One possibly important cue may be ship location relative to the horizon, which depends upon the pilot's height. The pilot may use this location cue by flying toward the dot, adjusting for any other information he has concerning the ship's motion. At this distance, the motion of the ship is probably below motion perception threshold.

The wake is a much more spatially extensive cue than the ship and it will appear as a line that will give the pilot direction information about the ship's heading. It may be a more potent cue for detecting position or location of the ship, because once you detect the wake, then you can follow that out and detect the ship itself. (Wake could also give a clue as to the sea conditions, e.g., if long and lean, a low seastate is implied.)

The position of the ship relative to the helicopter structure is a cue to ship's position relative to flight path. At this distance the task probably does not have a great deal to do with specific form features of the ship itself; it is a matter of getting location cues arranged properly in the field. This is reasonable, because the kinds of adjustments to the flight path are large relative to small spatial features of the ship.

STAGE 2: 4.5-2.5 MILES, "INSTRUMENTS"

> "...As you can see out here, we really can't make anything out of the lights that are there, so I'm primarily on instruments. We are passing just inside 4-1/2 miles. All I can tell is I'm below glideslope - this information I have by the red ball in the upper left-hand corner would indicate to me, as I would expect, I am below glideslope. There is virtually no deck information available to the pilot now when he sees green flashing light out on the horizon just because green is more intense, you pick it up, indicating to me that the ship is ready to receive me. It will be another two miles before I'll be able to pick up any deck information. So primarily for the next two miles I'll be flying almost 100% on instruments..." (Appendix A, III)

The pilot depends largely upon instruments. Power settings, communication instruments, heading and velocity, other information, etc., are monitored as an inside-the-cockpit task, although visual contact is employed too. It is known that co-pilots' roles may modify the ratio of "procedure following with head inside" to "visually perceived performance" (see Stage 4 excerpts). The visual aspect of this stage is one of spatial orientation, lineup, and positioning of the helicopter heading relative to the ship. Of course, closing velocity is available from the airspeed indicator. The information available in the cockpit via mechanical and electronic means may be more likely to be important for purposes of putting the helicopter into the correct position. Therefore, we believe the pilot will be making cognitive decisions based on radio beacon information at this point. The information the co-pilot provides also comprises a source of variability in the nature of the task. We have not yet sorted out these potential information sources and how they impact the perceptual aspects of the task.

STAGE 3: 2.5-1.5 MILES, "LINEUP"

> "...You look at the ball, you look at the lineup (you want to make sure you're directly on lineup and for that you check your strobes as you fly up the stern of the ship and they form a small "L" -- in other words, you look for the line to match both the drop and the stern of the ship itself)..." (Appendix A, I)

> "...Now we're presently at a little over or just under two and a half miles and you're able to start discerning where the lineup line actually is...the lineup line is forming a little bit of an "L". You can notice there's a slight appendage above the deck strobe. They are indicating that I was slightly off to the left so as a visual backup what I'll do is try and make that vertical line on the front of the hangar line up with the strobe lights that are on the deck and then the 2 red lights can drop down below the deck edge itself. The vertical drop lights are put there for exactly that reason..." (Appendix A, II)

> "OK, when that bar centers up you're just astern of the ship. See the yellow ball and the center VHI bar? When that centers up you're right on line. See you're right of the lineup. You can tell by the yellow ball, as well as your visual info, you're about 2-1/2 nautical miles away from the ship. You should be able to start picking up a little bit of cuing off the ship. You can see the red cross lines just below the strobes or the deck status: lineup line. You want to make sure that that red light is directly beneath the vertical light on the back of the hangar. This is what we are after. Now you can visually see in front of you also, look down you can see that you're about to lineup on the yellow bar on your CDI." (Appendix A, III)

At this stage in the landing the pilot is trying to position his aircraft directly behind the ship. Vernier acuity appears to be a very important visual cue. The pilot tries to line up the lineup line against the drop and stern of the ship itself. When the lineup line and the deck strobe form an L, misalignment is indicated and the pilot adjusts to get rid of the L. The pilot attempts to line the vertical lineup line on the deck with the strobe lights that are on the deck and align the vertical drop light up below the deck itself. The key visual dimension here is Vernier acuity so that high spatial frequency visual channels of the fovea are utilized. Aim point and relative positions of the ship and helicopter are inferred from the high frequency detail.

STAGE 4: 1.5-1.2 MILES, "RED-YELLOW INTERFACE"

> "...As soon as you find yourself on lineup, you look for the yellow ball - the yellow ball is what we use to visual intercept, allowing us to fly down a given glideslope at a given rate of descent...." (Appendix A, I)

> "...That orange ball is our glideslope indicator. I take it off my altitude hold. I start my rate of descent..." (Appendix A, II)

> "...(Now as the co-pilot is maintaining your engine gauges, etc., at this time?) Very much the same as a Mark I, he is a backup, he is primarily, in fact he spends more time visual and you spend more time on instruments until you are real close to the descent position and when that happens, he then switches primarily to instruments and you switch primarily to visual...." (Appendix A, III)

> "...So when I'm out here, all I'm doing is repeatedly going outside, taking a look, seeing if the yellow ball is coming in. I look down to make sure I am inside 1-1/2 nautical miles indicating the approximately correct position and then I do start my descent,...." (Appendix A, III)

The glideslope indicator system on the LAMPS MARK III consists of red, yellow, and green columnated beams of light. These beams are aimed so that the yellow beam is aimed along the indicated glideslope. Red is below and green is above it. As the pilot flies toward the ship (and through the glideslope), he would first see the red, then the yellow, and then the green balls, if he maintains exactly the same altitude. In attempting a landing, the pilot has his altitude hold on 400 feet while he sees the red ball, and then takes it off when he sees the yellow light. At this point he begins his descent. If he notes during his descent that the ball changes from yellow to red, he knows that he is below the appropriate flight path; if the ball changes to green, he knows that he is above the appropriate flight path. Obviously, color vision is important for this cue.

STAGE 5: 1.2-2.5 MILES, "DECELERATION"

"...You'll notice we've got a slight red ball there indicating we're on the bottom side of our glideslope, so I bring a little power in to level ourselves off. Continuing to slow down, about 60 knots, 200 feet is where you want to be, we're slightly left than the lineup line that means I'm looking at the lineup line on the ship. Turning slightly to the right to compensate for it..." (Appendix A, II)

"Notice our alignment is a little off, our heading is a little bit off, because we have a wind not directly on the bow of the ship and so we have to be able to crab, actually we crab the ship itself. Our rate of descent looks good. I look up, I do have a yellow ball and then check my altitude; make sure my airspeed and altitude are where I want to be.... all the time looking out periodically to make sure that my lineup is remaining fairly constant to the ship. Notice that the ship is rolling, it is rolling fairly significantly at around 8 degress. Notice we are approximately 60 knots, continuing to decelerate....our rate of descent looks good, closure rate looks good and we notice that we are just on the red and orange interface on the ball itself." (Appendix A, III)

(After 1.2 miles) "...It's real good where you are right now, if you look up there, you'll see you have the yellow ball, you're slightly left of lineup. Concentrate on that; the ship is barely moving - so that looks good, the yellow ball looks good, you are at approximately 200 now and you want to be at 60 knots. Now you've got a red ball. You pull some power in..." (Appendix A, IV)

Since the pilot reports that the ship is rolling at 8 degrees, we can infer that the spatial extent of the ship is great enough that features such as size, change in shape and size, and perhaps ship motion are available. Of course, we have no indication that these cues are actually being used by the pilot. The pilot says that the rate of descent looks good, and then he says that he looks up. It's clear from this statement that velocity is being monitored by instruments. The pilot continues to periodically monitor color of the glideslope indicator and the alignment of the lineup line and strobe lights so as to maintain proper heading.

STAGE 6: .25 MILES - FANTAIL. "APPROACH"

"...Now I'm still maintaining primarily visual outside, looking in at my airspeed in order to see my rate of descent. My rate of descent is a little too rapid, my rate of closure a little rapid, having to add a little bit of flare pulling power in...." (Appendix A, I)

"...Notice I'm just slightly to the left of lineup again. Checking the lineup lights on the ship itself. Continue to feedback after for 100 feet. Look for closure rate on the visual system itself. Presently we notice the closure rate is usually a little bit fast, so we are adding a little bit of flare to try to keep the yellow ball in sight." (Appendix A, II)

"...Closure rate is totally visual at this time, so we are going to go outside almost entirely, going to have to flare because our closure rate is a little bit too fast and try to keep the ship position in sight, so I'll pull in translational lift before we fall in across stern of the ship. Now we are just off the ship, I had to come to a hover because our closure rate was too high and the ship is moving..." (Appendix A, III)

(What are you looking at right now?) "The ball primarily also my closure rate looking at visual systems, watching the size change, and then looking at my airspeed and my altitude to make sure I'm not over-controlling the aircraft as far as the altitude OK..." (Appendix A, IV)

During this stage, the monitoring of closure rate changes from inside-instrument to outside-visual. Closure rate is monitored at least in part by noticing size changes (size constancy) (Haber and Hershenson, 1973; Kaufman, 1979). As the pilot closes, the task becomes one which is less an inferential task and more a direct vision/velocity monitoring task, where now the relative motion between his craft and the ship becomes the control task. The important cues at this time are mainly relative motion and perhaps absolute motion, size change and loom (Regan and Beverly, 1982).

Whereas heading and azimuth in the early stages of approach are monitored by ship position, monitoring in the later stages when closer to the ship is by motion. Both position and motion monitoring extract features of the ship to govern descent and aim point, but the latter capitalizes on motion perception - object motion, relative motion and motion parallax (Graham, 1965). As motion monitoring proceeds, the ship will grow so large as to occupy an extensive visual angle and focal vision must gradually transition to attend to smaller features which substitute for the objects whose edges become too large to provide focal information about position and descent rate. Another system (the ambient visual system) (cf., Leibowitz and Post, 1982) must now monitor and incorporate objects subtending large visual angles. The pilot continues to monitor lineup lines and lights, and the color of the glideslope indicator.

STAGE 7: FANTAIL - 15' HOVER (ABOVE DECK), "CREEP"

> "...We are going through translational lift as we cross the fantail. Actually want to cross the fantail at about 35 feet -- you'll notice we're at 36 feet right now - that's normally done visually on the outside and also presentation to the ship itself. You enter a creep about 20 knots looking primarily at the horizon and at where the ship motion is - you want to make sure that you don't come across when the ship is in a high roll angle..." (Appendix A, I)

An important cue during close approach is the horizon reference bar (or horizon). The pilot uses this to maintain level flight; in terms of roll, he "flies formation" on the reference bar. Doing this will keep him from adjusting roll according to the shape of the deck and hangar features which he is using to predict future deck angle. This prediction permits the pilot to select an occasion to cross the deck.

Cues important in crossing the fantail (stages 6 and 7) may be motion parallax (things moving behind other things); gradients of motion, probably involving the sea as well as the ship; disparity cues should become important under 200 feet and these disparity cues mostly concern the ship, rather than the ocean, because there are more and stronger contours on the ship than on the ocean. Binocular stereopsis is far more effective with contours than with simple textures (Chung and Berbaum, 1984). Changing disparity cues may also be important. Size and shape constancy and familiarity may also be very important in perceiving the deck motion.

STAGE 8: HOVER AT 15', "PRELIMINARY HOVER"

> "...You then translate forward looking down to .. in front of the pilot's chin window--he's able to pick up the safety line when he's hovering at about 15 feet above the deck and lined up with the vertical lineup lines in front of him. These are the horizon reference lines which is that lighted bar right in front of him to be able to determine whether it it himself or the ship that is actually moving. And he makes sure that he stays at least on the horizon. Most pilots will actually put the horizon somewhere between the horizon reference line and the top of the hangar face itself. For the lateral position, he

uses the vertical lines that are in front of him, you'll notice that one line is designed to go right between my legs and the other line should, with a certain amount of parallax, go between the ATO's legs. He uses fore and aft - he's normally conned by the ATO or he can look through the chin window himself and normally when he's in the right height, we will be able to pick up the white safety line in the upper left hand corner of the chin window itself and again get a pretty good indication that he's pretty close to the fore and aft lineup of the ship..."

"...(That bar with the dots on it is what you're using for a reference?) Horizon reference. As the ship rolls and we increase seastate, you see it move and you use that as a horizontal reference in the exterior space. As the ship is actually moving out from underneath you..." (Appendix A, I)

"...While we're in this position I basically am looking at the vertical lineup lines in front of me, the ones on top of the hangar trying to maintain position, I look down through the chin window that I described earlier, making sure the safety line is in the lower chin window. I also am periodically not moving my head, but using peripheral vision to pick up the LSO's console and being able to pick up the horizontal lineup line that is, that I was telling you about that had to be placed near the pilot's leg..." (Appendix A, II)

"...Then my job is basically to align myself up, using the vertical lineup lines you see in front of you placing them directly beneath my legs, using safety lines below me..." (Appendix A, II)

"...All I do is maintain position. Now notice that the horizon reference bar is now no longer stable as it was before. You can see it moving. The pilot will actually line up the right reference bar with the top of the hangar. If you notice, the right reference bar is low on the left end not perpendicular; it looks about 8 degrees. Now we're beginning to roll to the right. That's how we can usually tell what the ship itself is doing. That's how I'm keeping my position to it. As the ship rolls a little bit; I anticipate what it's doing - put slight flight control inputs to maintain my position over the deck..." (Appendix A, III)

"...The pilot has to continuously position himself and attempt to get back into position everytime he is blown out of position. By that he just has to lineup all the lines as I talked about before. The ship's moving fairly rapidly now, we all know the ship moves with variances in pitch and roll that are aperiodic, they are semiperiodic, but they then have high rolls and low rolls..." (Appendix A, III)

"Position is important to mention: left and right, fore and aft. People emphasize that, they look at it a lot, but also you're looking at the flight control on top of the hangar. ...when you put yourself in that position that is so you also can pick up pitch on a ship that way, as the stripes elongate, you know that either the aircraft is climbing or the ship is pitching nose up and they decrease in length, you know the ship is pitching down. You're able to keep track of pitch as well as your position, left or right, up or down."

"Of course, it's important to recognize when I say I'm looking for my position, I'm looking at the vertical stripes, yes I'm looking at the vertical stripes from left to right and the lineup line for fore and aft, but I'm also looking at those stripes to provide me more ship information and overall position in inertial space as the ship moves out from underneath."(Appendix A, IV)

"I'll guide you right in. Put the lineup line to the left on the right pair, the left lineup line on the starboard pair is right between your legs. You maintain your left and right with the lineup lines there, and our altitude is your horizon reference system itself"... (Appendix A, IV)

"I want to put the lineup lines with starboard pair right between your legs. Starboard pair of white lines right between your legs..."

"Right there, do you see the top of the hangar there, to maintain this position, this altitude you can tell when the ship starts pitching, the line disappears behind the...as the ship goes down and also watch your horizon reference. (I see it, that lower horizontal bar up there --- your dot lights.) Yes, you line this up and get good position and you can also watch for pitch that way.".... (Appendix A, IV)

It is clear from these extensive comments that hover at 15 feet is a very high workload situation. The pilot has to attend to many different inputs in order to make flight control inputs to maintain position over the deck. At slightly more than 15 feet above the deck, the pilot can watch the lines on top of the hangar that run fore and aft. When these lines elongate, either the aircraft is climbing or the ship is pitching nose up. When these lines decrease in length, the aircraft is either descending or the ship is pitching nose down. The vertical lineup lines on the hangar face are used to control lateral position, left and right, by lining up the lines between the pilot and co-pilot's legs. The horizontal reference lines and LSO's console seen in peripheral vision are used to control fore and aft positions. The white safety line through the pilot's chin window is also used to judge and confirm fore and aft position. Finally, the horizon reference bar is a reference to the external space; it allows the pilot to maintain level flight rather than flying level to the deck, which may be rolling and pitching. The pilot moves to an altitude where the horizontal reference bar is lined up with the top of the hangar. When the bar disappears behind the hangar or sticks up behind the hangar edge at an angle (interposition) (Woodworth and Schlosberg, 1954), the hangar bar angle indicates ship roll. Thus, there are at least five different visual cues which the pilot attempts to attend to. He's either time-sharing or trying to attend to these simultaneously. With more experience, the pilot probably either does a faster time-sharing or moves to more parallel kinds of monitoring. Motion parallax and interposition, shape constancy and peripheral vision appear to be the important visual perceptual dimensions for hover.

STAGE 9: HOVER AT 7', "HOVER TENSION"

"So all the pilot has to do then is to check a certain amount of power. The pilot then is ready to land. He still maintains position as he has been doing previously, he steps down to approximately 5-7 feet above the deck. To do this, although he can use his and he will use as a backdrop - he will look at this straight out primarily he just puts himself in a position where he is looking right at the ACO who is a man who actually sits in that little console you see out in front of you. Puts him right at his eye level, a little bit to the right. I'm drifting to the left - I'll bring myself back into position..." (Appendix A, I)

"If you look out your side window, you see a white stripe, that stripe should go right under the pilot's thighs, the lines in front of us should go between our individual legs allowing for parallax." (Appendix A, I)

"I will lower myself to about 5-7 feet above the deck and to do that all I do, is I look into the ACO's eyes, I want to maintain vertical position, I want to maintain fore and aft position using the lines I already described." (Appendix A, II)

Hover at 7 feet is a lot like hover at 15 feet. Of course, the pilot won't see the stripes on top of the hangar and will have more difficulty seeing the horizon reference system. The major additional cue is the ACO station which is right in front of him on the hangar wall. The pilot gets to the right position for rast pull-down by positioning the aircraft so that he can look directly into the ACO's eyes. He puts the ACO a little to his right so that he's in the proper left-right position. All that remains is for the aircrew to execute the rast pull-down procedure.

SECTION IV

DISCUSSION

The task, the subject, and the salience of visual cues, change throughout the approach. Good predictors of the early parts of hover-to-landing might be related to ability to position the aircraft in heading and azimuth. Perhaps during this stage the operator is mainly interested in lining himself up geometrically relative to the ship as opposed to, for instance, tracking closing velocity and trying to estimate the future location of an oscillating landing surface in an uncalm sea. During this part of the approach, a transition from one set of cues to another may take place. The latter may involve using more of the motion and binocular cues. Both simulator and real world may require more inference of spatial geometry earlier in the approach.

We believe that the first occasion that any visual input will have any bearing on a landing occurs at five miles or so. At five miles, the pilot may be able to detect the position of the vessel by observing its wake or the ship itself which will be very small in spatial extent. Wake sighting and ship recognition entails visual location (i.e., where in the scene is it?), probably by framing the ship in a canopy bow and then by slight continued attention to location monitoring. Proceeding from four and a half miles out, down to two and a half miles, the emphasis is upon instrument monitoring, where the pilot is obliged to follow certain set procedures. During this portion, the vision outside the cockpit which is required is largely inferential. The pilot's head is still in the cockpit for this, though the operator may be time-sharing with outside lineup cues visually. It is recognized that the co-pilot can function as a Ground Control Approach (GCA) type of feedback system. Beginning at two and a half miles, the approach becomes more a visual task. We consider that between 2.5 miles and 0.25 miles, the pilot is attempting to do position tracking, and his main objective is to keep his aircraft lined up with respect to heading and azimuth. We speculate that at about 0.25 miles, the visual perceptual job changes from one which is largely position tracking to one of rate tracking. The pilot now makes determinations of velocity and motion, and there are few perceptual judgments which involve inferential spatial determinations.

While these general notions of how the landing task is performed may be of heuristic value, we have also gathered a great deal of very specific information about the visual cues which are used at particular distances. These visual cues may form the basis for augmented feedback experiments at VTRS. Table 3 summarizes the visual cues, perceptual inferences, and perceptual channels which are used in the first nine stages of the landing task (see Appendix B for diagram and figures which illustrate some of these cues).

TABLE 3. TEN STAGES OF THE HOVER TASK WITH PROPOSED VISUAL CUES AND PROCESSES

Stage	Range	Visual Cues	Visual Tasks and Mechanisms
1	5-4.5 mi.	ship - a tiny dot wake - a tiny line	visual search, acuity, high spatial frequency on sensitivity
2	4.5-2.5 mi.	as above only slightly larger	minimal visual tasking - monitor position of ship
3	2.5-1.5 mi.	deck lineup lines, deck strobe lights, vertical drop lights	Vernier acuity, high spatial frequency sensitivity
4	1.5-1.2 mi.	glideslope indicator lights - red, yellow, green (stage 3 cues)	monitor glideslope ball color, color vision (continued stage 3 visual tasking)
5	1.2-.25 mi.	ship shape, orientation size (stages 3 and 4 cues)	(stages 3 and 4 visual tasking)
6	.25-fantail	ship size, sizes of smaller features (stages 3 and 4 cues)	<u>focal vision</u> - size constancy provides distance, familiar size provides scale <u>ambient vision</u> - motion of large features drive vestibular egocentric self motion (stage 3 and 4 visual tracking, stage 3 cues may now be inspected by motion parallax detection rather than static high spatial frequency mechanisms)

TABLE 3. (cont'd)

Stage	Range	Visual Cues	Visual Tasks and Mechanisms
7	fantail-15' hover	horizon reference or horizon/ship motion (stage 6 cues)	horizon reference is monitored to maintain level flight to avoid flying formation with the ship; stance stability mechanisms ship motion is monitored to predict future deck angle; visual thinking and three-dimensional judgment
8	hover at 15'	vertical lineup lines on the hangar (lined up between pilot and co-pilot's legs)	lateral position (left and right); parallax or interposition
		horizontal reference lines and LSO's console (Rast Control Station)	fore/aft position; whether the ship is moving out from under you; peripheral vision
		white safety line through chin window	fore/aft position; interposition
		stripes on top of hangar elongate <u>or</u>	either the aircraft is climbing or falling <u>or</u> the ship is pitching nose up; shape constancy
		decrease in length	ship is pitching nose down
		horizon reference - the pilot gets to an altitude where the right horizon reference bar is lined up with the top edge of the hangar	reference to exterior space - when the bar disappears behind the hangar or sticks up beyond the hangar edge, the angle of bar and hangar angle indicates ship roll; parallax, interposition

TABLE 3. (cont'd)

Stage	Range	Visual Cues	Visual Tasks and Mechanisms
9	7' hover	ACO console (position to look at ACO eyeheight) (same cues as in stage 8 except hangar top stripes)	vertical height left and right position

VISUAL STIMULUS DIMENSIONS VS VISUAL CHANNELS

To the extent that position stability and motion are important cues, vection will also be important (Dichgans, Held, Young, Grant, 1972; Dighgans, 1977; Dichgans and Brandt, 1978). In daytime flight, a horizon and a surface plane which represents the ocean below help the pilot keep the aircraft in the appropiate position as an air foil. The way in which this works as performed by pilots probably entails a fairly direct link between the ambient, or large field, visual system which is responsible for stance stability and apparent position stability. The ambient system comes in again during close approach such that motion perspective and parallax cues become important. The ambient part of the visual system, from 20 degrees eccentric to 60 degrees eccentric, is critical for perceiving self-motion based on visual cues (Leibowitz and Post, 1982). We believe that the last 500 feet or so of the landing is conducted using changing size as a cue to distance and closing velocity (Leibowitz, 1984). During the period that the ship is 500 or more feet away, it probably occupies 20 or less degrees retinal angle, maybe 30 or less. Within the last 50-75 feet, the ship probably fills the cockpit. Therefore, somewhere along our distance dimension, either the ship as a size-change cue ceases to be a ship-size-change and now becomes a deck- or a hangar door-, man-, or ladder-, or whatever-size-change, and/or another cue or channel is used to perform the task. A pilot probably learns, perhaps unconsciously, how to smooth out this transition as he learns his task. Therefore, whatever threshold function is available for the ship-size-change function, a different set of threshold data must apply for the other features if they are used for familiar size. For a particular spatial extent on the ship (e.g., the width) at 500 feet away, this is going to be a cue for the focal visual system; the system that looks for fine detail, analyzes objects, recognizes familiar forms. But during the last 50 to 75 feet this extent, too, is going to be retinally too big to be primarily a focal visual system cue and will now become a cue for the ambient visual system. Stated differently, this same cue is going to provide information to two very different kinds of visual information processing systems (focal and ambient). The focal visual system is a visual system that takes information from memory, makes comparisons with the retina, makes inferences about distance based on size-distance invariance, and may be modifiable by practice; the ambient visual system, on the other hand, is built to do very different things. The ambient visual system is ontogenetically earlier and is less likely to be modifiable. It takes visual information from a large area of the visual field and computes self-motion directly, which is not done in the focal visual system. This becomes particularly important in a simulator, where there are not appropriate vestibular cues, but only linear vection (Dichgans and Brandt, 1978) cues available. The pilot's rapidly and directly perceived velocity, position in space, and orientation in space, will all be determined by the visual analysis of large features in this last 50 to 75 feet. The more mediated percepts will include size and shape familiarity comparisons.

RECOMMENDED EXPERIMENTAL CUE AUGMENTATIONS

1) An augmented feedback cue for visual sighting of the ship from TACAN indications should be tested in an experiment at ranges between 5 - 4-1/2 miles. This cue, which should probably be in red lines, should be an envelope across the visual scene for visual search based on TACAN indications. Additional augmentations involving the ship wake may be of value in this distance range.

2) A second augmented cue, for the distance range starting at 2-1/2 miles, might be an accentuated lineup line and lights. Again, these may be done in red and superimposed over the lineup line and lights that are normally present.

3) A third cue, for the distance range beginning at 1.2 miles, would be augmentation of the glideslope indicator ball. When the glideslope indicator is red, you are under the glide-slope. When it changes to an orange and then an amber, you are actually on glideslope. If you go beyond glideslope, it is green. Because the pilot flies at 400 feet altitude until he gets the yellow ball, some augmented feedback may be necessary if this yellow ball or amber ball is overshot. Perhaps a vertical line of 9 balls, 2 red on the bottom, 5 yellow in the middle, and 2 green on top with one of the balls lighted, could

be used to provide more precise cue information. From 1.2 miles to the edge of the fantail, three different augmented cues are possible. During this time, the pilot is monitoring lineup with the lineup lines and lights and glideslope with glideslope indicator and also his deceleration. At the top of the glideslope this is done using instruments and at the bottom it is a visual job using ship size change. Thus, the two cues mentioned earlier, accentuated lineup line and lights and accentuated glideslope ball indicator, may be used.

4) A fourth augmented cue could indicate whether deceleration is correct. This cue might be auditory rather than visual, or if visual, it would have to be inside the cockpit.

5) At the bottom of the glideslope, the augmented cue for deceleration should be visual outside the cockpit. Pilots have indicated that they use size change in this part, so it should be some augmentation cue to indicate deceleration that draws attention to size change. Having crossed the fantail and flying hover at 15 feet above the deck, hover augmentations may be very efficacious for training because the pilot is having to do a number of things at once. Because the ship is moving, the pilot is essentially flying formation with the deck of the ship. This is a problem because if the ship is rolling, the pilot wants to maintain his position over this deck but doesn't want to maintain his orientation with the deck; rather he wants to maintain orientation with the horizon reference bar or the horizon itself.

6) A sixth possible augmented cue for hover would be accomplished by accentuating the horizon reference bar when oscillations of the aircraft in orientation (deviations from level) coinciding with deck motion are detected. At the same time, the lineup lines may be accentuated (e.g., by flashing). Since the lineup lines also provide information about the orientation of the deck surface, augmenting these cues under deviation from level hover may be of value.

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APPENDIX A

Protocal of the SH-60B Flight Simulator (Singer Link) Landings Aboard Ship

Roger McTighe from Essex Corporation flew with LCDR Larry Cable the training officer from HSL-41. Larry Cable is a test pilot school graduate and followed the SH-60B completely through the flight test and acceptance of the aircraft and the dynamic interface with the ship. He has approximately 1000 small ship landings with about 380 RAST Landings (Haul Down) in the SH-60B and total flight time of about 1,700 hours. Roger McTighe has about 500 shipboard landings and 5,000 flight hours.

All landings were at night and were essentially on instruments using TACAN for lineup until visual cues from the ship could be picked up. There are no visual cues on the side until you hover over the ship. Cable stated and McTighe concurs that in an actual landing aboard ship you pick up side cues from the wave tops and from the wake that helps you with lineup.

INCOMPLETE PROTOCOL AT LANDING #1

...actually quite good, about 80 knots. You look at the ball, you look at the lineup, you want to make sure you're directly on lineup and for that you check your strobes as you fly up the stern of the ship and they form a small 'L' --in other words you look for the line to match both the drop and the stern of the ship itself.

As soon as you find yourself on lineup, you look for the yellow ball - the yellow ball is what we use to visual intercept, allowing us to fly down a given glideslope at a given rate of descent. It is actually quite still at about 80 knots (375 feet per minute), so periodically the pilot has to look down and see what his rate of decent actually is - we are presently at about 400 feet/begin rate of descent and we are looking at the yellow ball - it seems pretty constant. Now on this particular aircraft because we do fly right up the stern, we have to do a constantly decelerating sitdown, so I have to continue to check power to make sure that as I slow down I do not lose either airspeed too quickly or rate of descent too quickly. When I pass to 100 feet, I have to look at it; I want to pass through 100 feet at approximately 50 knots, so I won't have to flare as much when I get to the bottom. Now I'm still maintaining primarily visual outside, looking in at my airspeed in order to see my rate of descent. My rate of descent is a little too rapid, my rate of closure a little rapid, having to add a little bit of flare pulling power in. We are going to through translational lift as we cross the fantail. Actually want to cross the fantail at about 35 feet--you'll notice we're at 36 feet right now - that's normally done visually on the outside and also presentation to the ship itself. You enter a creep about 20 knots looking primarily at the horizon and at where the ship motion is - you want to make sure that you don't come across when the ship is in a high roll angle. You then translate forward looking down to .. in the front of the pilot's chin window--he's able to pick up the safety line when he's hovering at about 15 feet above the deck and lined up with the vertical lineup lines in front of him. These are the horizon reference lines which is that lighted bar right in front of him to be able to determine whether it is himself or the ship that is actually moving. And he makes sure that he stays at least on the horizon. Most pilots will actually put the horizon somewhere between the horizon reference line and the top of the hanger face itself. For the lateral position, he uses the vertical lines that are in front of him, you'll notice that one line is designed to go right between my legs and the other line should, with a certain amount of parallax, go between the ATO's legs. He uses fore and aft - he's normally conned by the ATO or he can look through the chin window himself and normally when he's in the right height, he will be able to pick up the white safety line in the upper left hand corner of the chin window itself and against a pretty good indication that he's pretty close to the fore and aft line up of the ship. (We're sitting at 15 feet)* Approximately 15 feet above deck. (What's the red mark on the left there that blips on and off?) What you're looking at -- that's the stablized glideslope indicator and we are below, because we're not on this 3 degree glideslope anymore, we are below what the actual glideslope is when sitting here in a hover and what you're seeing is we're moving out the lens focal area of that GSI itself. (That bar so far with the dots on it is what you're using for a reference?) Horizon reference.

As the ship rolls and we increase seastate, you'll see it move and you use that as a hoizontal reference in the exterior space as the ship is actually moving out from underneath you. When we're in this position, the sensor operator in back will actually lower the messenger cable which is a small line that's

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* Items in parentheses are by Roger M. Tighe.

being lowered from the aircraft to the deck. A man on the deck actually hooks the haul-down cable, or a heavy cable, up to the aircraft itself and then we pull that--we have a electric winch that pulls that heavy cable up into the aircraft and locks it into a main probe. When it's locked into the main probe, the sensor operator in back gets a 4 green - all that means is that the main probe is down, the tail probe is up, the messenger cable is in and locked, and the main cable is in and locked and he says, "Well, I've got 4 green hover tension". All that means is that the pilot gets on radio - he relays that information to the LSO on the deck. The LSO then applies approximately ... he starts out by just reeling in the main cable at 2 feet per second --when it reaches...when it's all reeled in it goes to a standby condition which is 850 pounds of force and then when it goes to hover tension, that increases to approximately 2000 lbs. of force applied to the bottom/belly of the aircraft. The whole time the pilot maintains his fore and aft, left and right, primarily as we described. When the pilot's ready to land then, he lowers himself to approximately 5 to 7 feet above the deck. (Why don't you hold it right here and I'll get a shot, O.K.? can you do that?) OK you want it up at 15 feet? (Yeah, just put it in the hover position.) This is where the pilot does most of his flying during the RAST landing. (Put it in your hover position and I'll take a picture of it).

(Just start in again what you were doing here.) OK. So he gives a 4 green requesting hover tension - what the LSO then does. So all the pilot has to do then is to check a certain amount of power. The pilot then is ready to land. He still maintains position as he has been doing previously, he steps down to approximately 5-7 feet above the deck. To do this, although he can use his and he will use as a backdrop - he will look at his straight out. Primarily he just puts himself in a position where he is looking right at the ATO who is a man who actually sits in that little console you see out in front of you. Puts him right at his eye level, a little bit to the right. I'm drifting to the left - I'll bring myself back into position. OK, now he's about in position - he needs those ready to land. OK, when he's ready he says "ready to land"; the LSO applies 4000 lbs tension, the pilot does not have any power, the aircraft comes down. What you've actually been doing is applying 4000 lbs thrust deficit to the aircraft instantaneously and you come down at approximately, that was 6 feet/sec. You land between 6-9 feet/sec normally. If you look out your side window, you see a white stripe, that stripe should go right under the pilot's thighs, the lines in front of us should go between our individual legs allowing for parallax. (OK, why don't we go back out and sight the ship and call out miles and altitude.)"

COMPLETE PROTOCOL AT LANDING #2

"At about 5 miles we should be able to see outside if we fly out far enough. The ship has a 1.5 degree slope to the deck and because of it, many times, not in the simulator but in the ship itself, you can't see the strobe. And so some of the hard parts are just being able to fly to a given position primarily on the TACAN. In fact, that's where I am now, just got the rate of turn in necessary to try and roll out behind the ship on the TACAN and then I'll try and fly in the lineup. What the pilot is doing here is periodically looking out his right window to see if he can pick up the ship yet. And I do have some lights out in the distance and that's what I'll be doing to try to line myself up in using the TACAN as my primary scan because you're essentially flying night and instrument. And my peripheral scan will be through the visual system trying to establish in part where the ship is - all pilots have a tendency to rely on eyesight above and beyond everything else that's given. You notice my TACAN shows I'm almost dead astern of the ship itself, and because of that I will increase my roll even though looking at the lights out there, there is virtually no way I could tell exactly where I am. All I can see is a lot of blinking lights out there. Remember this is a dusk environment; in the night environment it becomes even harder to determine position. The first thing I'm going to be looking for is as you basically can see out there - just barely you're able to differentiate a red light in the upper left hand corner; you see a green flashing that indicates a deck status and you see what looks like just a white dot. If you consider most pilots have reasonable eyesight, but that white dot is actually going to break itself down into your lineup line itself as we get a little bit closer in. So the pilot looks for the white dot out there and tries to make sure on instrument he's able to line himself up behind the ship, compensating for wind if he can. I look down at the TACAN then periodically to determine what position is to make sure my airspeed is still where I want it to be. Actually I have altitude hold engaged presently, so I look at the altitude about once every 3 or 4 scans at the instruments. Even though there are dots out there, the pilot routinely looks down at his VHI to determine what his position is relative to the ship and tries to take larger and larger cuts to compensate for wind until he's able to fly exactly down the ship in accordance with the instruments that he has available to him. Now we're presently at a little over or just under two and a half miles and you're able to start discerning where the lineup line actually is.

As I said before the lineup line is forming a little bit of an "L" you can notice there's a slight appendage above the deck strobe. They are indicating that I was slightly off to the left so as a visual back up what I'll do is try and make that vertical line on the front of the hanger line up with the strobe lights that are on the deck and then the 2 red lights can drop down below the deck edge itself. The vertical drop lights are put there for exactly that reason. Now periodically the pilot continues to look back in, about 1.5 nautical miles, we know that in another three tenths of a mile we're actually going to come up and have to begin our descent. We are 1.6 nautical miles, we see the ball's beginning to go orange. That orange ball is our glideslope indicator. I take it off my altitude hold. I start my rate of descent. What I'm actually doing is taking enough power off that I can start my rate of descent at the vertical speed that I know is the appropriate vertical speed for the GSI and the airspeed I've started. I'll have to put a little power in as I slow down. What I want to do is keep the ball out in front yellow. Continue looking in - I glance at the TACAN right now - 1.1 nautical miles. We're approximately 300 feet - we're on the high side of our allowed glideslope. I add a little bit more power taking off to increase my rate of descent somewhere between 500 feet per minute. Now I know that if I slow down, it's going to take a little bit less power so I'm easing back on the stick. You'll notice we've got a slight red ball there indicating we're on the bottom side of our glideslope, so I bring a little power in to level ourselves off. Continuing to slow down, about 60 knots, 200 feet is where you want to be, we're slightly left than the lineup line that means I'm looking at the lineup line on the ship. Turning slightly to the right to compensate for it. My rate of descent has again increased back up to about 375 feet per minute. I need to go back down, I want to pass 100 feet at approximately 50 knots, so I'm having to look at the altitude scanning, it -- the rad out, looking outside for the ball, looking at what my airspeed is, I continue to use that. Noticing what my VSI is indicating to me to make sure that I'm not increasing my rate of descent too rapidly.

Notice I'm just slightly to the left of lineup again. Checking the lineup lights on the ship itself. Continue to feedback after for 100 feet. Look for closure rate on the visual system itself. Presently we notice the closure rate is usually a little bit fast, so we are adding a little bit of flare to try to keep the yellow ball in sight. Keeping ourselves under control going to translation left before we can cross the deck edge itself. My cross-deck edge is about 35 feet. We're crossing at about 34 feet so we're under control at a creep. Presently we tell the LSO to lower the messenger cable. He would be in back and he would lower the messenger cable. While he's doing that I position myself over the alternate line. This allows people on the deck not to have to stumble over the RFP while we're landing. So he lowers the messenger cable and then you have to lower in the neighborhood of 25 feet of cable to enable them to move it about. While we're in this position I basically am looking at the vertical lineup lines in front of me, the ones on top of the hangar trying to maintain position, I look down through the chin window that I described earlier, making sure the safety line is in the lower chin window. I also am periodically not moving my head, but using peripherial vision to pick up the LSO's console and being able to pick up the horizontal lineup line that is, that I was telling you about that had to be placed near the pilot's leg. When the sensor operator has retrieved the cable, he says, "I have 4 green", I relay that information to the LSO. The LSO then says, "Roger, standby" and he adds then the hover tension that I talked about before.

When he does that, all I do is to not fight it, but we will feel the aircraft itself being pulled to the left as it centers over our RSV itself. I have to have a little bit of power because he basically has to add 2000 lbs. for hover tension itself. Then my job is basically to align myself up, using the vertical lineup lines you see in front of you placing them directly beneath my legs, using safety lines below me which the ATO is generally conning me--he provides me verbal communication--telling me where I am aboard the ship, so if I lose that safety line as the ship rolls, I'm not going to get out of position. When I feel comfortable, feel that I am in basic position, and the aircraft feels good to me - that I am in a good position, I will lower myself to about 5-7 ft. above the deck and to do that all I do, is I look into the ACO's eyes, I want to maintain vertical position, I want to maintain fore and aft position using the lines I already described. Lower myself 5 feet up to 7 degrees above the deck itself and tell the LSO I am ready to land. The LSO then waits for the ship itself and maintain position and when he feels we are in a good position, and we have a reasonable expectation of making a successful and comfortable, feel that I am in basic position, and the aircraft feels good to me - that I am in a good position, I will lower myself to about 5-7 ft. above the deck and to do that all I do, is I look into the ACO's eyes, I want to maintain vertical position, I want to maintain fore and aft position using the lines I already described. Lower myself 5 feet up to 7 degrees above the deck itself and tell the LSO I am ready to land. The LSO then waits for the ship itself and maintain position and when he feels we are in a good position, and we have a reasonable expectation of making a successful landing he will then add 4000 lbs.

When he adds 4000 lbs., he is actually conning me back there, telling me what my position is, when in a good position for him, he will say, "standby, standby, land now", he has 4000 lbs., "down, down, down." His pole will be in the trap. If we're in the trap, you will then close the beams and lock us in. We are actually in the aft part - on the outside of the trap. Is that where we are, John? Yeh, not a good position.

John, go to Page 45, look for a turbulence it should be around Number 24 or 25, in that ballpark and make it about a 4. Thank you very much."

COMPLETE PROTOCOL OF LANDING #3

"I've got in the neighborhood of 380 landings. Yeah. I've got the highest number in the Navy. How long with the program? I picked up the last dynamic interface testing at NADC and I've been with it the whole time every time it's gone testing to sea except one. I've had the opportunity to fly it; a lot of other people have not had.

OK, I'm doing the same thing I did before, just using primary guages as far as using TACAN to line myself up as if it were an instrument approach. Periodically I look out the window and I'm definitely able to pick up the dots on the horizon, indicating that the ship is there. (How far are we out now?) We're presently a little over 4-1/2 miles, (4.5 at what altitude?) 400 feet. (400 feet) A normal pattern is flown at 400 feet. (That's your commencement altitude?) Yes, it is. TACAN needles indicate that I should be directly astern of the ship. Because of that I'm going to increase my turn. As you can see out here, we really can't make anything out of the lights that are there, so I'm primarily on instruments. We are passing just inside 4 -1/2 miles. All I can tell is I'm below glideslope - this information I have by the red ball in the upper left hand corner would indicate to me, as I would expect, I am below glideslope. There is virtually no deck information available to the pilot now when he sees green flashing light out on the horizon just because green is more intense, you pick it up, indicating to me that the ship is ready to receive me. It will be another two miles before I'll be able to pick up any deck information. So primarily for the next two miles I'll be flying almost 100% on instruments.

What I'm doing now, as I look up at the ship, is making sure that I still have the info I thought I had. And then I go back down into my VHI to make sure that my turn indicator indicates that I am flying level - that I am in balanced flight, my altitude remains constant. (Now is the co-pilot maintaining your engine gauges, etc., at this time?) Very much the same as a Mark 1, he is a backup, he is primarily, in fact he spends more time visual and you spend more time on instruments until you are real close to the descent position and when that happens, he then switches primarily to instruments and you switch primarily to visual. We're getting a couple of beeps, little bit of an anomaly in the visual system out here. You get off there to the right. That is nothing. That isn't related....We're about 2.5 miles, so I have to start thinking about what I want to look for, so I'm trying to pick out what deck position I have and trying to make sure that I don't get any indications off the deck that are different than I would expect them. Notice that the red light is changing just a tad; it's going into a little bit of an orange. So I look down, I say "Yes, I'm at 400 feet". I'm about 2.1 nautical miles, a little bit far out to begin my descent, so we know we're still on the bottom side of an interface, waiting for the ball itself to turn to an amber, because that's the color we want the ball itself. (We're still at 400 ft.) Remain 400 feet until we actually get a good solid yellow ball and then we begin our descent. (Yellow ball for glideslope indication?) Yes.

So when I'm out here, all I'm doing is repeatedly going outside, taking a look, seeing if the yellow ball is coming in. I look down to make sure I am inside 1-1/2 nautical miles indicating the approximately correct position and then I do start my descent, recognizing that this air speed I want to be approximately 375 feet per minute rate of descent. I have taken my radar altimeter hold off by reaching over and striking the radar altimeter push button on the automatic flight control system and I start my descent down.

Notice our alignment is a little off, our heading is a little bit off, because we have a wind not directly on the bough of the ship and so we have to be able to crab, actually we crab the ship itself. Our rate of descent looks good, I look up, I do have a yellow ball and then check my altitude; make sure my airspeed and altitude are where I want to be. We're 70 knots right now, about 250 feet. I want to drop to 60 knots at approximately 200 feet so I've got to take a little more power off and lean back on the cyclic itself. All the time looking out periodically to make sure that my lineup is remaining fairly constant to the ship. Notice that the ship is rolling, it is rolling fairly significantly at around 8 degrees. Notice we are approximately 60 knots, continuing to decelerate. We're approaching 50 knots--50 knots is the magic point where our EFCS changes into an altitude retension system from an airspeed retension system. Fifty knots at 100 feet is exactly where we want to be. Our rate of descent looks good, closure rate looks good and we notice that we are just on the red and orange interface on the ball itself. Closure rate is totally visual at this time, so we are going to go outside almost entirely, going to have to flare because our close rate is a little bit too fast and try to keep the ship position in sight, so I'll pull in translational lift before we fall in across stern of the ship. Now we are just off the ship, I had to come to a hover because our close rate was too high and the ship is moving. I want to go across the ship deck edge at approximately 35 feet and we were in fact at 36 feet across the deck itself. I know I'm going to be using the starboard track-trap provided for me by the LSO upon final. I will then place myself as I talked about before. Left and right lateral lineup will be with the lineup lines on the alternate position not over RSV that we're going to be landing on, but the alternate position and our sensor operator will be lowering the cable. John, if you'll take care of that for me, please. (Messenger cable going down?) Roger that.

All I do is maintain position. Now notice that the horizon reference bar is now no longer stable as it was before. You can see it moving. The pilot will actually lineup the right reference bar with the top of the hangar. If you notice, the right reference bar is low on the left end not perpendicular; it looks about 8 degrees. Now we're beginning to roll to the right. That's how we can usually tell what the ship itself is doing. That's how I'm keeping my position to it. As the ship rolls a little bit; I anticipate what it's doing - put slight flight control inputs to maintain my position over the deck. Notice that it's increased to about 8-10 degrees there, I have to have a little bit of cyclic to maintain my position. That's actually wind that's blowing us off to the left, the spillover transpires around on the deck itself. What I do is I see the ship rolling rapidly now so I want to have a little bit of cyclic in the opposite direction to counteract the spill over that is going to happen around the ship edge -- that's exactly what happened, I got caught in the spill over. (4 green) Roger that, standby then, and the pilot has to continuously position himself and attempt to get back into position everytime he is blown out of position. By that he just has to lineup all the lines as I talked about before. The ship's moving fairly rapidly now, we all know the ship moves with variances in pitch and roll that are aperiodic, they are semiperiodic, but they then have high rolls and low rolls that are totally dependent on the ship height, the ship motion before the roll occurred, the ship's speed, modal period, height of the wave and how the aircraft or the ship's actually responding to each one of the previous waves. That's all planned in here, so that's why you have high roll areas and low roll areas. Right now the pilot doesn't have to wait till he gets to a low roll area. And because I have 4 green back here I have to work very hard to maintain my position.I would basically tell the LSO that I had 4 green and request hover tension. (Roger, hover tension.) What he will do, then he will reel in all the heavy cable, and when it is in, he will add (hover tension) 2000 lbs. hover tension, what I want to do is allow him to pull me in above trap itself making sure that I don't fight it. If you do, it's like a sling shot, it brings you right in above the trap. I add a little bit of power. OK John, just a second. I add a little bit of power to counteract the 2000 lbs he's applying. But what it does do is it attempts to center you above the RSV itself. And you see my flight control, or my work load as measured by flight control magnitude and frequency is significantly reduced. I'm going to maintain this position until I reach another quiescent around the ship and then I would tell him I'm ready to land. All I want to do is maintain approximate position of the ship not drift too far out. Looks like it's slowing down so then I would tell him as it comes down....that I'm ready to land. Now if he sees that the ship has about a 5 degree roll right, so he's kind of wait until it levels out and give me a little bit of conning. OK, John, whenever you're ready. Make sure the ship is less than about 5 degrees for the landing. (OK, you're right over.) OK go ahead. (down, down, down.)That's a successful landing of seastate 2. (What were the max rolls?) 16 degree rolls in a dusk-night situation."

SELECTED COMMENTS OF THE PILOT WHILE COACHING THE INTERVIEWER THROUGH A LANDING

(Concerning hover) "Over the deck I get myself into a workload situation where I'm not commenting on everything I'm looking at. It's probably important that I make sure especially for your job, that I reinterate for you what I'm actually looking at out there. Position is important to mention: left and right, fore and aft. People emphasize that, they look at it a lot, but also you're looking at the flight control on top of the hanger. You notice you can just barely see the...when you put yourself in that position that is so you also can pick up pitch on a ship that way, as the stripes elongate, you know that either the aircraft is climbing or the ship is pitching nose up and they decrease in length, you know the ship is pitching down. You're able to keep track of pitch as well as your position, left or right, up and down. The stripe is very important ---the pilot has a... as you Mark I pilots know, you look at various stanchions and these positions all give you peripheral cuing of where the real position actually is. Of course, it's important to recognize when I say I'm looking for my position, I'm looking at the vertical stripes, yes I'm looking at the vertical stripes from left to right and the lineup line for fore and aft, but I'm also looking at those stripes to provide me more ship information and overall position and inertial space as the ship moved out from underneath, OK.

(At about 3.5 nautical miles astern of the ship) When you look down there, you can see you are a little left of lineup. I'd recommend taking a crab trap to about 080, maintain a 080 all the way down and sometime in the middle, you'll find out your on lineup. OK, when that bar centers up you're just astern of the ship. See the yellow ball and the center VHI bar? When that centers up you're right on line. See, you're right of the lineup. You can tell by the yellow ball, as well as your visual info, you're about 2 -1/2 nautical miles away from the ship. You should be able to start picking up a little bit of cuing off the ship. You can see the red cross lines just below the strobes or the deck status: lineup line. You want to make sure that that red light is directly beneath the vertical light on the back of the hangar. This is what we are after. Now you can visually see in front of you also, look down you can see that you're about to lineup on the yellow bar on your CDI. So everything is coming together for you, about 2.2 nautical miles. We've got a mile to go.

(After 1.2 miles) It's real good where you are right now, if you look up there, you'll see you have the yellow ball, you're slightly left of line up. Concentrate on that; the ship is barely moving - so that looks good, the yellow ball looks good, you are at approximately 200 now and you want to be at 60 knots. Now you've got a rate of descent too high . You notice that you've got a red ball. You pull some power in. That's fine, you don't want to add too much - you can overpower the aircraft if engine climb load is too much. You've got a green ball out there you know to drop power back down.

(The pilot is putting the Helo into position between 500 and 35 feet. What are you looking at right now?) The ball. Primarily also my closure rate looking at visual systems, watching the size change, and then looking at my airspeed and my altitude to make sure I'm not over-controlling the aircraft as far as the altitude OK. Here's where you start to creep and lower to about 35 feet."

HOVER TO LAND

"I'll guide you right in. Put the lineup line to the left on the right pair, the left lineup line on the starboard pair is right between your legs. You maintain your left and right with the lineup lines there, and our altitude is your horizon reference system itself, so you want to come a little bit left and a little bit forward..a little forward and you probably got around 10 feet to go forward, altitude is in the neighborhood of 10 feet high, still about 5 feet to go forward. I want to put the lineup lines with starboard pair right between your legs. Starboard pair of white lines right between your legs.

Right there, do you see the top of the hangar there? To maintain this position, this altitude, you can tell when the ship starts pitching, the line disappears behind the... as the ship goes down and also watch your horizon reference. (I see it, that lower horizontal bar up there --- your dot lights.) Yes, you line this up and get good position and you can also watch for pitch that way."

APPENDIX B

Diagrams of LAMPS MK III Figures Showing Available Visual Features at Several Stages in the Landing Approach

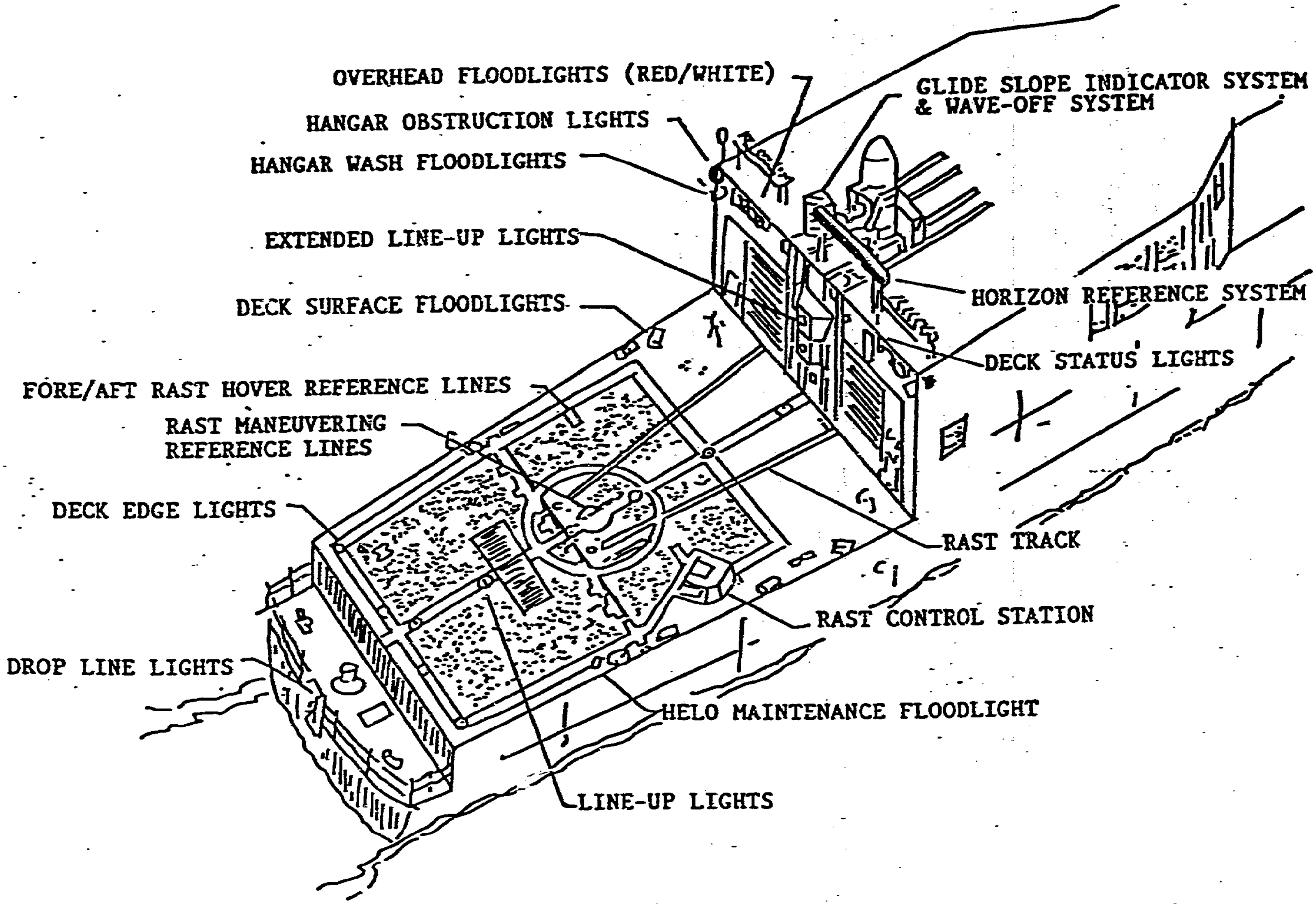

Figure B-1. Typical LAMPS MK III VLA System for Air Capable Ships.

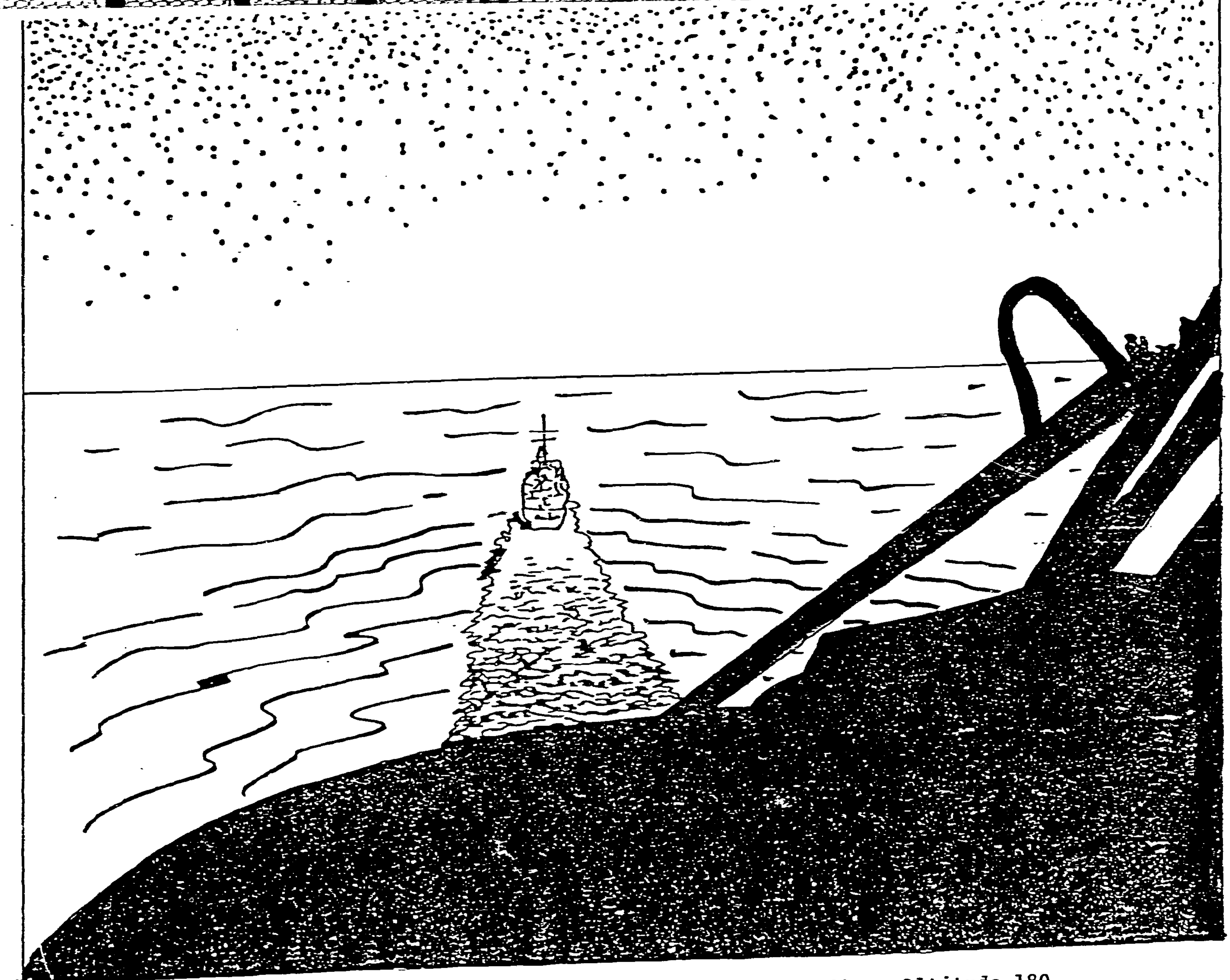

Figure B-2. Approach-ATO Window. Range 0.4 Miles, Altitude-180 Feet. (Phase 5)

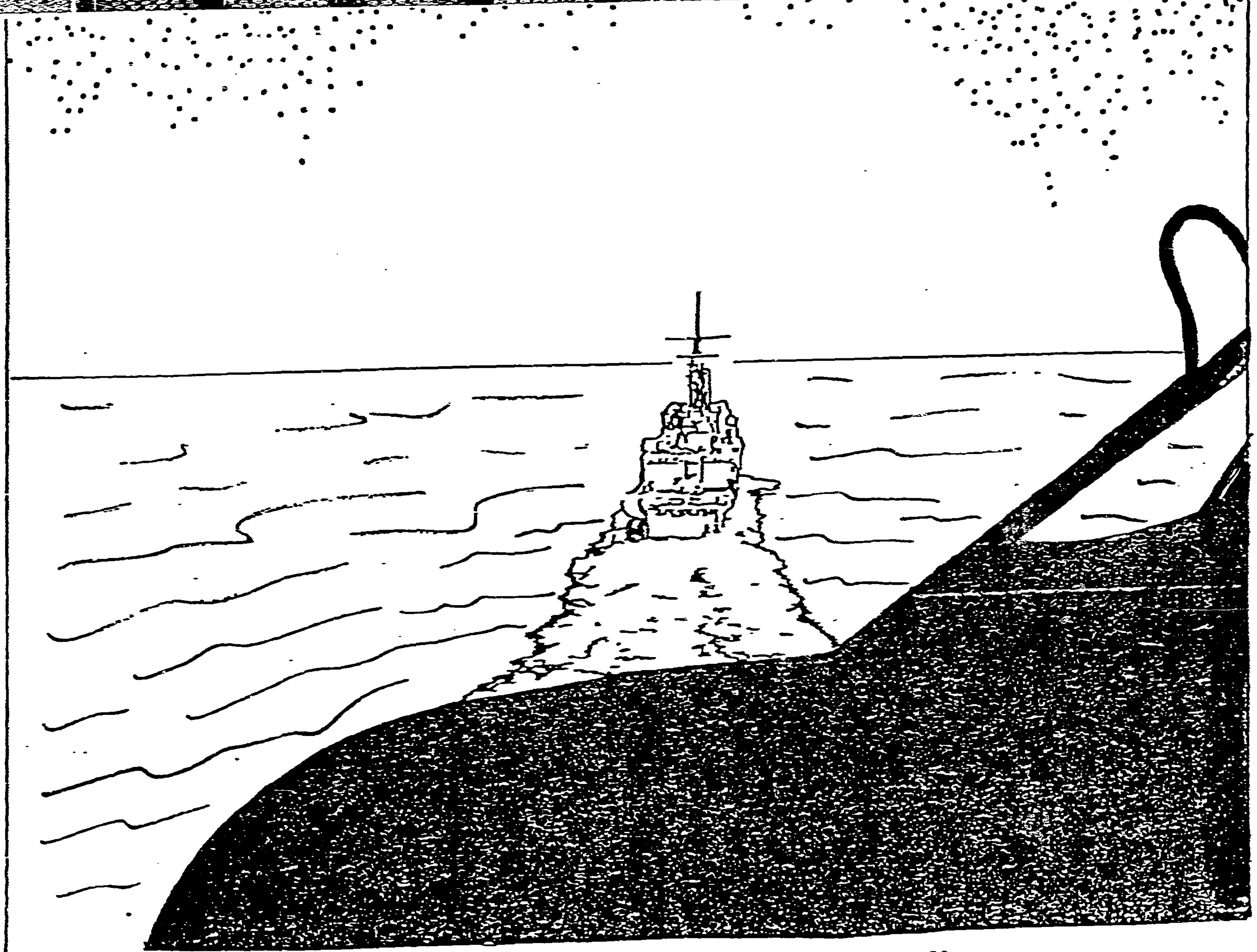

Figure B-3. Approach-ATO Window. Range 0.2 Miles, Altitude - 63 Feet (Phase 6)

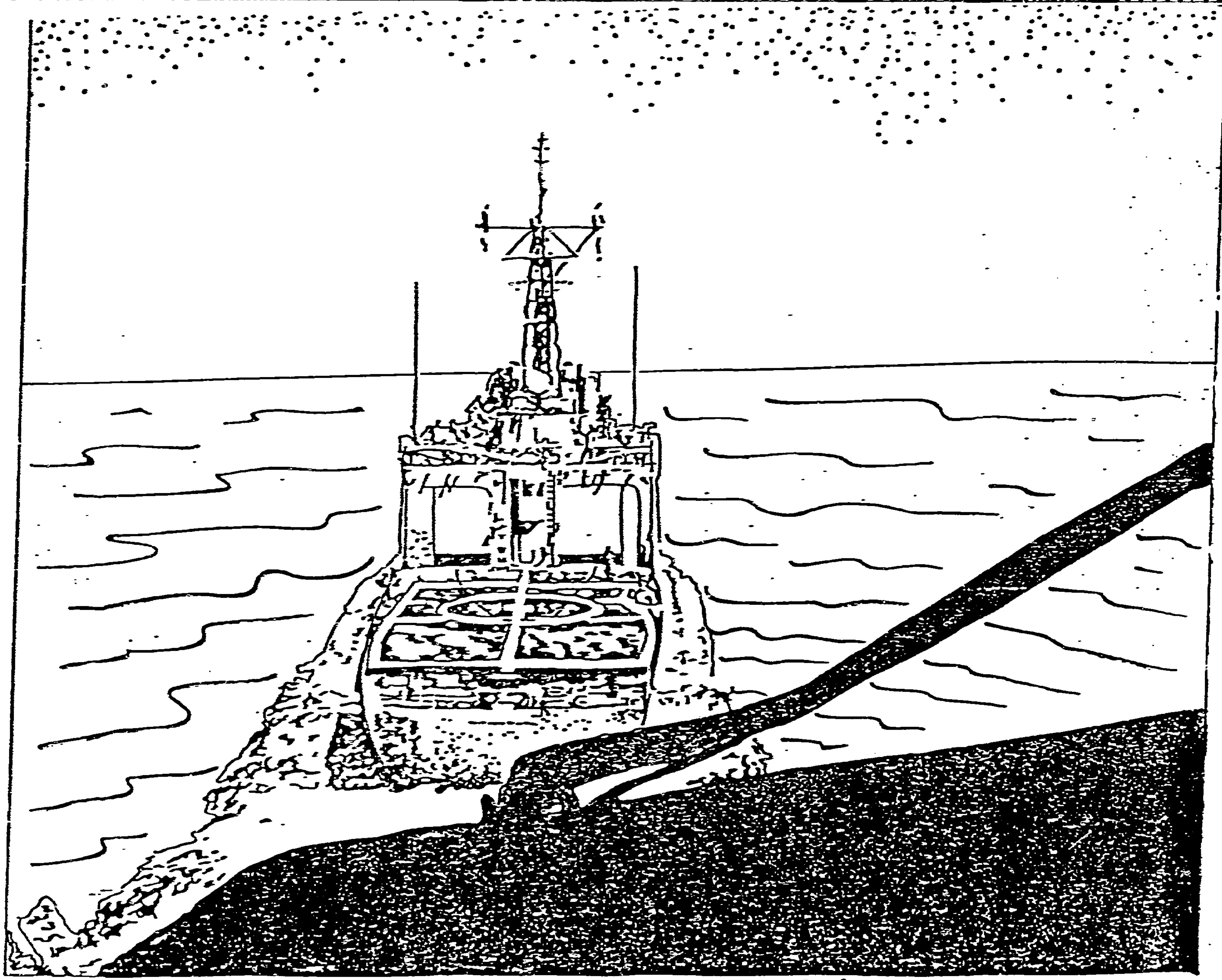

Figure B-4. Approach-ATO Window. Range 0.1 Mile, Altitude - 30 Feet (Phase 7)

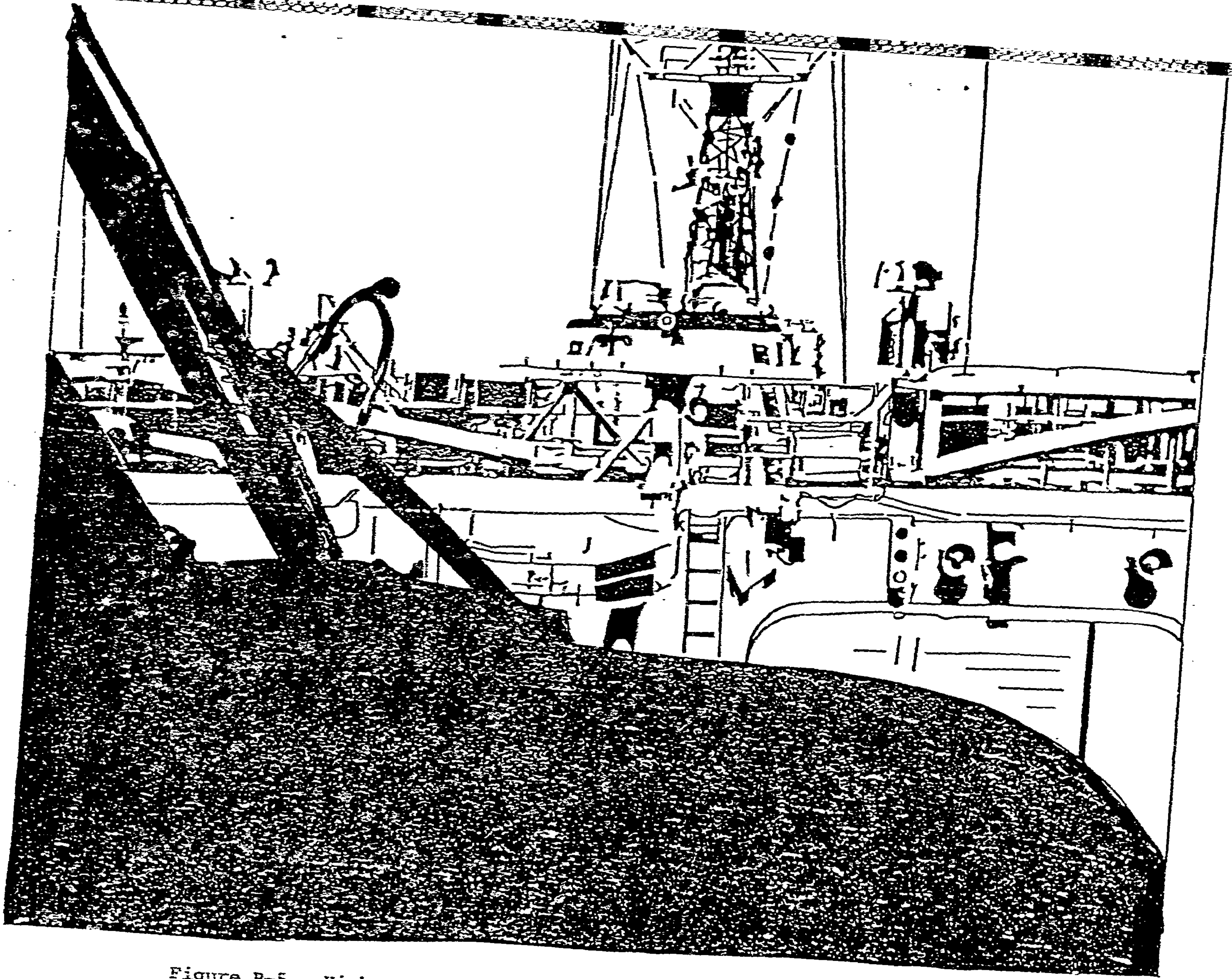

Figure B-5. High Hover, Pilot's View. (Phase 8)

Figure B-6. Low Hover, Side Straight Out, Pilot's View-port RSD. (Phase 9)

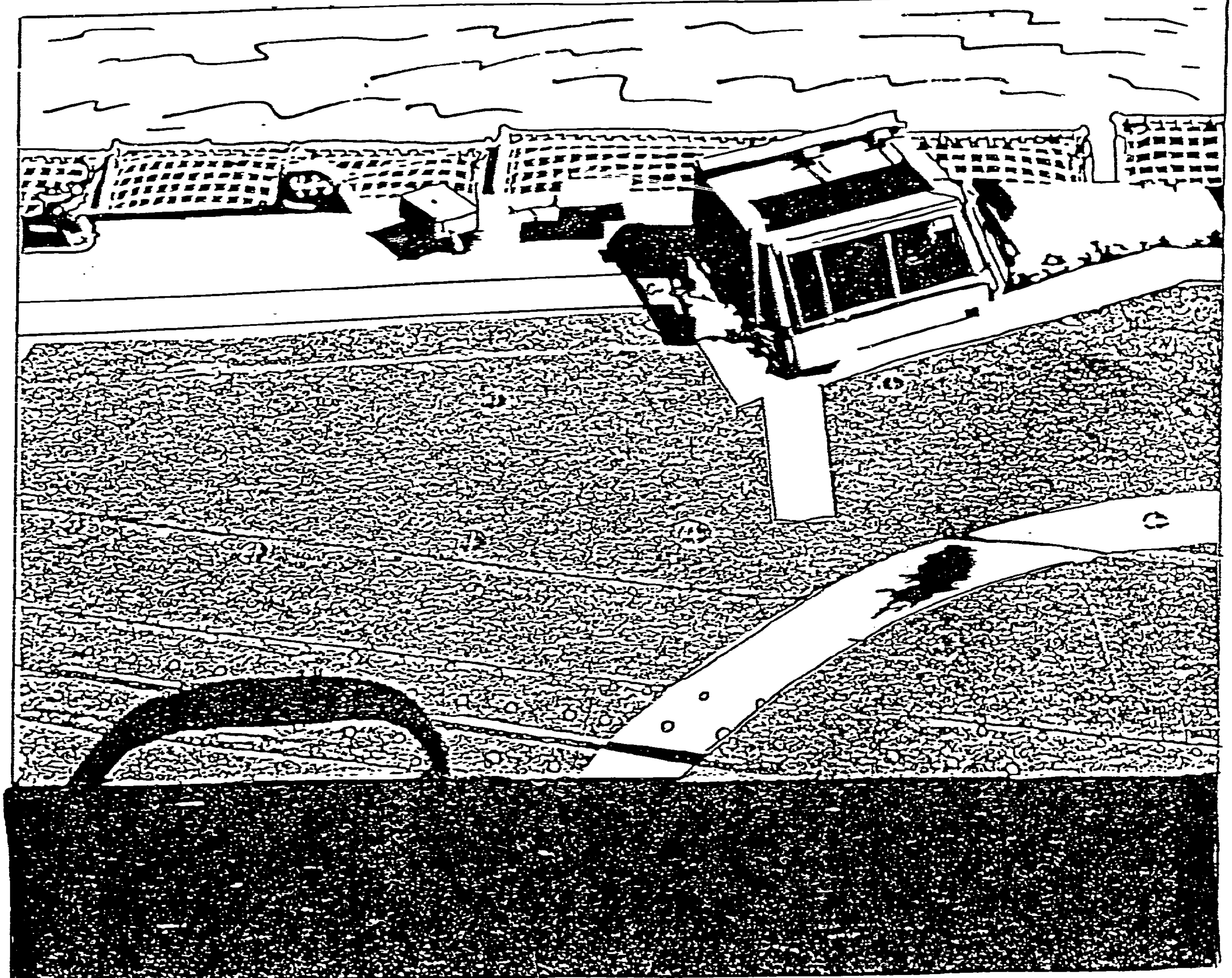

Figure 7-B. Low Hover, Side Angle Down, Pilot's View (Phase 9)

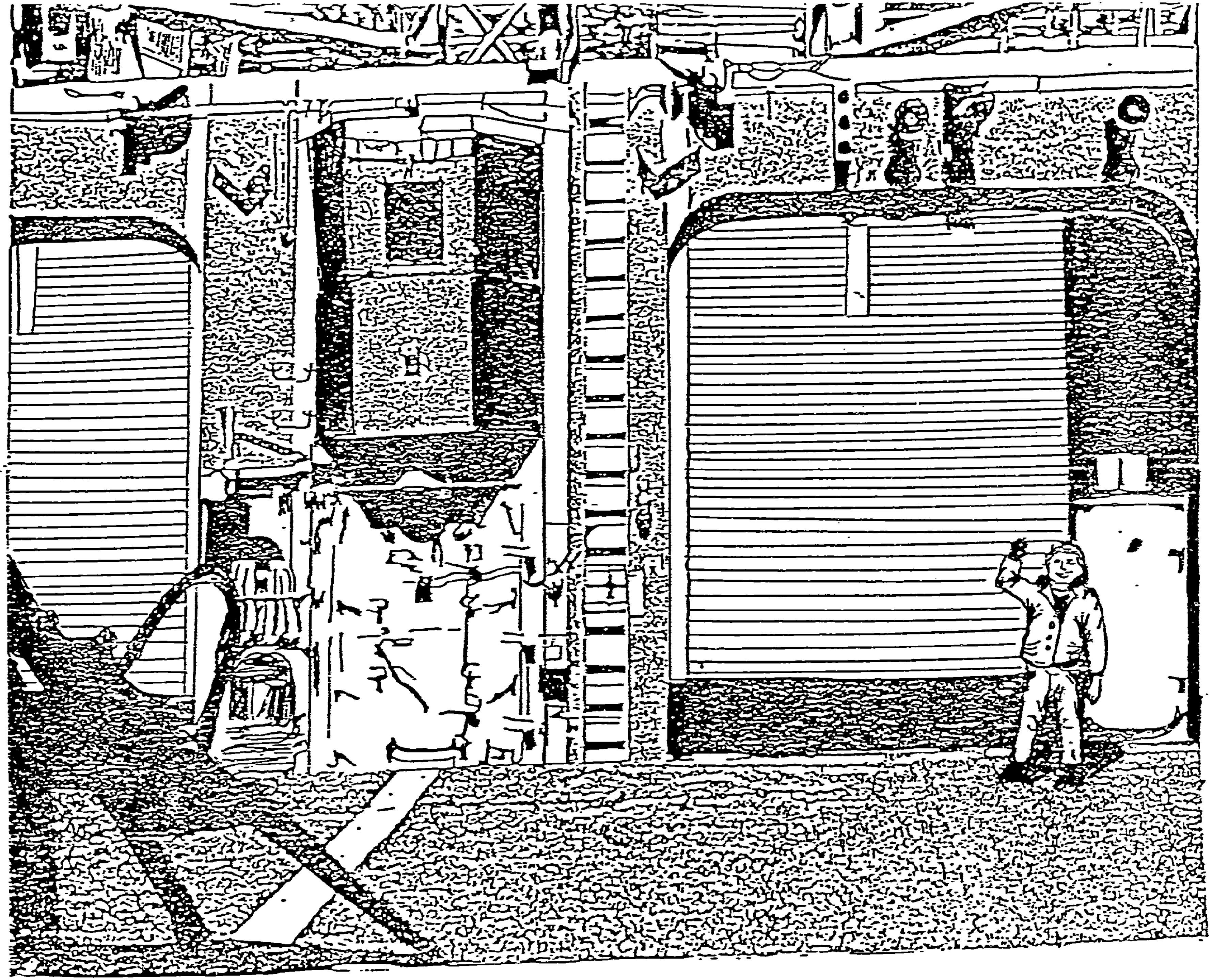

Figure B-8. On Deck, Straight Out, Port RSD, Pilot's View (Phase 10)

APPENDIX C

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